REMARKS/ARGUMENTS

Claims 1-10 and 12-27 remain in this application. Claims 1 has been amended. Claim 11 has been cancelled by a previous amendment.

Claims 1, 4, 6-8, 13, 15, 17, 18 and 25-27 are rejected under 35 USC 103(a) as being unpatentable over Kawanishi et al (US 6,404,966 B1).

I. Claim 1 has been amended to state that the band gap structure has non-circular holes. This amendment is supported, for example, by Fig. 7 of the Applicants' specification. Such band gap structure is not disclosed by the Kawanishi et al (US 6,404,966 B1) reference. Accordingly, claim 1 and its dependent claims 4, 6-8, 13, 15, 17, 18 are not obvious over this reference.

II. Furthermore, Claim 1 states that "the optical energy is guided in a mode having a nonlinear refractive index of less than about 10^{-18} cm^2/W." As discussed in the previous amendment, this parameter contributes to the low loss and is not taught or disclosed by the cited reference. In fact, pg. 7, paragraph [0033] of the Applicants specification discloses that in conventional fibers the guided modes have effective nonlinear refractive indices n_2 ranging from $2x10^{-16}$ cm^2/W to $4x10^{-16} cm^2/W$ while some of the Applicants claims call for it being less than 10^{-18} cm^2/W . (This is at least a factor of 10 different (or about 20 times less) than that of the conventional fibers.)

On page 2 of the Office Action dated 3/6/2006 the Examiner stated that the "references teach achieving this index by using air filled holes to guide the optical energy in PBG fibers. Applicants own disclosure identifies the nonlinear index of air to be $2.9x10^{-19} cm^2/W$ which is within the claimed range."

Applicants respectfully traverse the grounds for this rejection, for the following reasons:

Applicants understood the Examiner's statement as saying that: (i) the references teach fibers with hollow (air filled) cores and that air has a nonlinear refractive index of 2.9×10^{-19} cm^2/W, and (ii) thus it should be obvious that a mode propagating in such fiber will have an effective nonlinearity of 2.9×10^{-19}, which is less than about 10^{-18} cm^2/W. This conclusion can be logically reached if and only if *all* of the light is carried in the hollow-core region. However, this is not how FBG fibers work. (However, if Applicant's misunderstood what Examiner is saying, it is requested that the Examiner provide a more detail explanation of the rejection.)

Applicants disagree with this assumption and suggest that it is not at all obvious that hollow-core fibers support a mode with such low nonlinearity (less than 10^{-18} cm^2/W). A recent publication (see enclosed) by C. J. Hensley, D. G. Ouzounov, A. L. Gaeta, N. Venkataraman, M. T. Gallagher, and K. W. Koch, "Silica-glass contribution to the effective nonlinearity of hollow-core photonic band-gap fibers," Opt. Express 15, 3507-3512 (2007)) teaches:

> "The optical field is primarily localized in the air core, <u>but since the nonlinear refractive index of glass is roughly 1000× larger than that of air, it is not obvious which medium dominates the effective nonlinearity of the fiber</u>. It was shown [5] that the effective nonlinearity of the fundamental mode of the fiber described in Ref. 3 is approximately equal to that of the air in the fiber core. Alternatively, theoretical analysis of other commercially available HC-PBGFs [6, 7] concluded that glass and air regions have comparable contributions to the total nonlinearity. Lægsgaard *et al.* [14] showed theoretically that the fraction of light that resides in the silica regions, and thus the glass contribution to total nonlinearity depends strongly on the air-filling fraction." (Emphasis added.)

Thus, it is clear that the <u>presence of an air core alone is insufficient in determining the nonlinearity</u> of the refractive index of the optical mode in the fiber waveguide.

A simple calculation illustrates the problem:

- Nonlinear refractive index of air:

$$n_{2,air} = 2.9 \times 10^{-19}\ cm^2/W \tag{1}$$

- Nonlinear refractive index of silica:

$$n_{2,glass} = 2.6 \times 10^{-16}\ cm^2/W \tag{2}$$

If we consider the nonlinear refractive index to be a simple weighting of the fraction of the optical intensity in the glass (we will denote this fraction as f) and the fraction intensity of the light in the air (thus, 1-f) we find:

$$n_2 = f \times n_{2,glass} + (1 - f) \times n_{2,air} \tag{3}$$

Claim 1 sets the limit on the nonlinear refractive index n_2 of the optical mode to be less than 10^{-18} cm^2/W. From equation (3) we must then have:

$$2.6 \times 10^{-16} f + 2.9 \times 10^{-19} (1-f) < 10^{-18}, \tag{4}$$

or:

$$\mathbf{f < 0.11\%.} \tag{5}$$

Thus, less than 0.11% of the light is propagating through the glassy region of the cladding. Those skilled in the art recognize that <u>it is not obvious</u> that one can achieve less than 0.11% overlap of the light in the glass, because the optical mode always has some significant overlap with the cladding (or else one could remove the cladding with no effect).

It was <u>Applicants</u> who taught that it *is* possible to have a photonic band gap fiber that guides an optical mode (guided by a band-gap cladding) such that <u>the optical energy is guided in a mode having a nonlinear refractive index of less than about 10^{-18} cm^2/W</u> i.e.- it was applicants who taught that it *is* possible to have a mode that propagates with very little overlap with such silica portion of the cladding. Applicants do not find that the references (from *Kawanishi et al*, *Libori et al* and *Fajardo et al*) enable or teach or suggest how to achieve such small overlap with the glass in their structures, or that such small overlap is even possible. A recent (see enclosed) reference (J. Lægsgaard, N. A. Mortensen, J. Riishede, and A. Bjarklev, "Material effects in air-guiding photonic bandgap

fibers," J. Opt. Soc. Am. B **20**, 2046-2051 (2003)) has the following discussion of overlap with the glass for air holes of diameter *d* separated by a pitch Λ:

> For the design with d/Λ = 0.88, where 7–9% of the field energy is in silica, the material dispersion ranges between ~0 and -200 ps/nm/km, whereas for the design with d/Λ = 0.95 and only 2–3% of the field energy in silica, the material contribution to the GVD ranges between -50 and 50 ps/nm/km.

These ranges (7% to 9% and 2% to 3 %) are much larger than 0.11% that corresponds to the non-linear refractive index of nonlinear refractive index of less than about 10^{-18} cm^2/W called for in claim 1 and its dependent claims.

The mode overlap with the glass decreases as the air-filling fraction is increased. With circular holes this is accomplished by increasing the diameter *d* of the air holes. However, Applicants' calculations show that for circular holes (such as those shown by the cited references-i.e., *Kawanishi et al*, *Libori et al* and *Fajardo et al* references), an overlap of greater 1.7% (see calculated data in Fig. 1, below) between the optical mode and silica based cladding is achieved when the air holes just touch, d/Λ = 1.00.

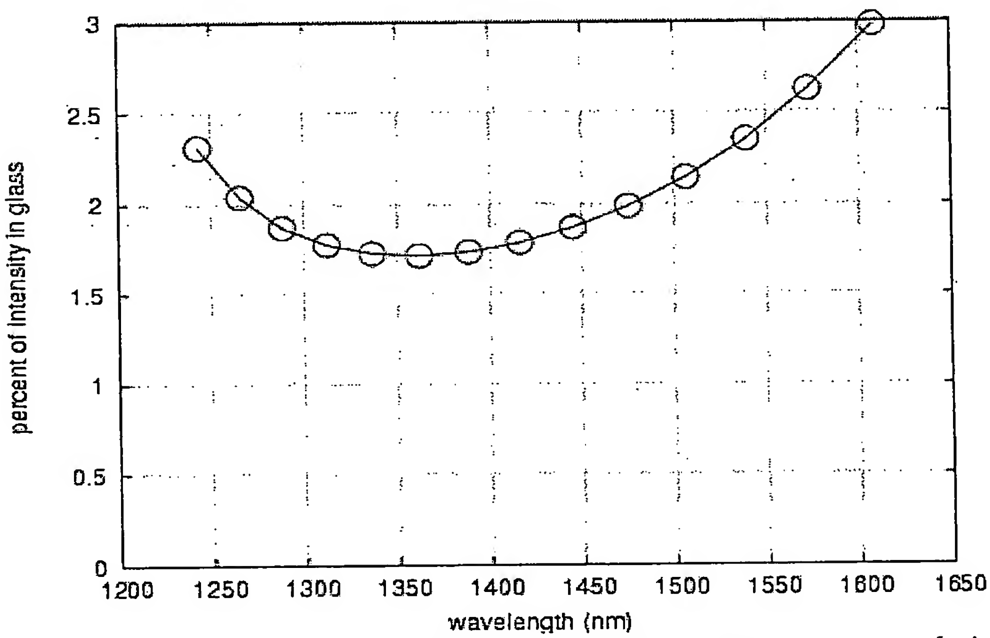

Fig. 1. Calculated overlap of light with glass for a PBGF structure of circular air holes (refractive index n=1) in silica (refractive index n=1.45), air-hole diameter of d=3.5 μm, and hole-to-hole spacing or pitch of Λ=3.5 μm. The holes are just touching.

This value is insufficient to reach the low nonlinearity claimed by Applcants. In fact this value is about 10 times larger than the required overlap calculated above, and Applicants do not believe that a further reduction of 10X is obvious or enabled by this reference. Any further increase in the size of circular holes without the change in pitch (hole separation) leads to a **disconnected unphysical structure.**

Applicants achieved small overlap between the guided mode and the cladding of the PBG fiber, for example, by using structures with *non-circular* air holes (shown in our Figure 7 in original patent application) and/or very large airfilled ratious, which structures are not disclosed by the cited reference of *Kawanishi (nor is it disclosed by Libori et al* or *Fajardo et al).* Accordingly, claim 1 is note obvious over the cited reference(s).

Claims 4, 6-8 13, 15, 17 and 18 depend from claim 1 as their base claim and, therefore, explicitly incorporate the language of claim 1. Accordingly Applicants respectfully submit that claims 1, 4, 6-8 13, 15, 17 and 18 are not obvious over the Kawanishi reference.

III. Claims 25-27 (and 13) state that the "optical fiber is configured to support a temporal soliton having a peak power of greater than about 1 MW". Such fiber is not disclosed by the Kawanishi reference, and the Kawanishi reference provides no incentive for having a fiber with this characteristics. Accordingly, claims 13 and 25-27 are not obvious over this reference.

The Examiner, in replying to Applicants' previous response stated that "Kawanishi et al also teach that the optical fiber can be used to transmit pulses (see column 1, lines 60-63). As discussed above, the non-linear refractive index results in minimal pulse spreading. Therefore, the pulse will retain its shape. Pulses such as these are solitons. One of ordinary skill in the art recognizes the benefit and desirability of high power

signals. It would be obvious to one of ordinary skill in the art at the time of invention to use an optical soliton pulse having a peak power of 3MW …"

Applicants respectfully disagree with this statement for the following reasons:

Retaining its shape is a necessary but *not sufficient* condition to define a soliton. The term soliton was coined in 1965 to reflect the particlelike nature of solitary waves that remain intact even after mutual collision. The following excerpt is from an authoritative source (G. Agrawal, "Fiber-Optic Communication Systems," (Wiley & Sons, New York, 1997) p. 468) on optical fiber communications (also enclosed):

> The existence of fiber solitons is the result of a balance between *group-velocity dispersion* (GVD) and *self-phase modulation* (SPM), both of which, as discussed in Sections 2.4 and 5.2, limit the performance of fiber-optic communication systems when acting independently on optical pulses propagating inside the fiber. One can develop an intuitive understanding of how such a balance is possible by following the analysis of Section 2.4. As shown there, the GVD broadens optical pulses during their propagation inside the fiber except when the pulse is initially chirped in the right way (see Fig. 2.12). More specifically, a chirped pulse can be compressed during the early stage of propagation whenever the GVD parameter β_2 and the chirp parameter C happen to have opposite signs, so that $\beta_2 C$ is negative. SPM, resulting from the intensity dependence of the refractive index, imposes a chirp on the optical pulse such that $C > 0$. Since $\beta_2 < 0$ in the 1.55-pm wavelength region, the condition $\beta_2 C < 0$ is readily satisfied. Moreover, since the SPM-induced chirp is power dependent, it is not difficult to imagine that under certain conditions, SPM and GVD may cooperate in such a way that the SPM-induced chirp is just right to cancel the GVD-induced broadening of the pulse. The optical pulse would then propagate undistorted in the form of a soliton.

As mentioned above, in optical fibers there <u>are two main forces that cause pulses to spread: self-phase modulation (SPM) and group-velocity dispersion</u> (often referred to simply as dispersion). An important note is that group-velocity dispersion has several sources: material dispersion, waveguide dispersion, modal dispersion and profile dispersion (see G. Agrawal, "Fiber-Optic Communication Systems," (Wiley & Sons, New York, 1997) pp. 39-49, enclosed). A fiber with an air core has near-zero material dispersion but may have significant waveguide, modal and profile dispersion.

One might expect that an optical pulse traveling through a medium with low nonlinearity would not spread. However, this argument does not consider the spreading due to group-velocity dispersion. None of the cited reference addresses or discusses this issue. Accordingly, Applicants' claims are unobvious over these references.

Applicants are claiming an optical fiber and optical fibers inherently have at least the waveguide form of group-velocity dispersion referred to above. Even if it is possible to eliminate the other forms of dispersion, it is impossible to eliminate *waveguide* group-velocity dispersion at all wavelengths in an optical waveguide. Typically there may be one or more discrete zero-dispersion wavelengths in an optical waveguide, however, by analytic continuation one may not have zero dispersion over a continuous range of wavelengths unless dispersion is zero everywhere (and this is impossible in a waveguide).

A pulse in time implies a finite spectral width and thus, from the argument above, must include wavelengths at which dispersion is non-zero. Thus such a pulse will spread due to dispersion unless balanced by another mechanism.

Thus, it is not sufficient to have only low nonlinearity or only low dispersion to support a soliton pulse. The cited reference(s) teach nor make obvious the formation of solitons in hollow-core fibers. The Libori et al reference mentions solitons in the context of conventional fibers (column 1 lines 13-20) but it is not obvious, for the reasons explained above, that this concept can be extended to hollow-core fibers, or band-gap fibers, and the recited reference(s) do not suggest that this can be done. The extension to soliton propagation in hollow-core fibers is not obvious. For instance, the examiner has argued that it is obvious that hollow-core fibers have low nonlinearity because they have a low nonlinearity core. This is logically true only if all of the light is carried in the core region. Let us suppose, arguendo, that is true—then we propose to evacuate such a fiber. Now, in the absence of a core material the core nonlinearity is zero. However, as discussed above, such a fiber will not support a soliton because there is no nonlinearity to balance the waveguide dispersion. Fortunately the "obvious" argument that all

of the light is carried in the hollow region is flawed and Applicants discovered, as taught in the present application, that photonic band-gap fibers can indeed support solitons.

Accordingly, claims 13, and 25-27 are not unpatentable over Kawanishi et al (US 6,404,966 B1).

It is noted that Applicants balanced the pulse spreading by designing fibers that use SPM, a result of the fiber nonlinearity, to cancel the inherent group-velocity dispersion of the fiber. This nonlinear effect leads to a chirp of the optical pulse as described in the reference above. The optical fiber nonlinearity is always greater than zero as a result of the intrinsic properties of the glass and this sign determines the nature of the pulse spreading (leads to C>0, longer wavelengths move ahead of the shorter wavelengths). This nonlinear chirping is proportional to the intensity of the optical pulse. To balance the spreading from this chirping Applicants' waveguide fibers have the group-velocity dispersion in the fiber which has opposite effect, such that shorter wavelengths travel faster than longer wavelengths. If the fiber is designed correctly *and* the pulse intensity is correct, it is possible to achieve a balance over an extended wavelength range that includes the pulse spectrum. In such a fiber, nonlinear SPM cancels the anomalous group-velocity dispersion and the optical pulses can propagate without spreading, giving a rise to solitons, as disclosed and claimed by Applicants. However, this is not an obvious solution, and the air filled cores, generally do not support solitons, nor make it obvious on how to do it.

Claims 1-3, 5, 6-10, 13, 14, 16-18 and 25-27 are rejected under 35 USC 103(a) as being unpatentable over Libori et al (US 6,792,188 B2).

I. Claims 1-3, 5, 6-10, 13, 14 and 16-18 call for a bandgap fiber having a core region surrounded by a "cladding region including a photonic band gap structure <u>with non-circular holes</u>, the optical energy having a wavelength within the photonic band gap of the photonic

band gap structure". Such fiber is not disclosed by the Libori reference. Plase note that although Fig. 34 of Libori shows a microstructured fiber, this fiber is not a bandgap fiber because the fiber of Fig. 34 has solid core with an index of referaction higher than the surrounding structure.

II. Furthermore, as discussed above, Applicant's claims 1-3, 5, 6-10, 13, 14 and 16-18 specify that "the optical energy is guided in a mode having a nonlinear refractive index of less than about 10^{-18} cm^2/W", and this feature is not shown, disclosed or discussed by the Libori reference. As shown above, one of skill in the art will recognise that the nonlinear refractive index of less than about 10^{-18} cm^2/W corresponds to a fiber that has a very small overlap between the mode and the fiber cladding structure. This feature is not obvious, because no cited references taught or disclosed that it is even possible to achieve the minimal required overlap between the optical mode and the cladding structure surrounding the core (less than a fraction of 1%), and no cited reference shows any embodiments capable of achieving it.

More specifically, the Examiner pointed that "Labori et al teach that PBG structure can include air holes. Air has a nonlinear refractive index of $2.9x10^{-19}$ cm^2/W which is within the claimed range." As discussed above, the presence of air alone is not enough to bring the nonlinear refractive index of the guided mode within the range claimed by the applicants. The Libori reference does not disclose, teach, or suggest what is required to achieve the low non-linearity claimed by the Applicants. The Libori reference also does not provide any enabling examples that teach how to achieve the "optical energy is guided in a mode having a nonlinear refractive index of less than about 10^{-18} cm^2/W".

III. Morever, as discussed in the previous Response, although Libori makes a statement that a low loss fiber is desirable and can be achieved with PBG structure, Libori does not define what is meant by a "low loss", nor provides an enabling embodiment of the PBG structure that has the losses in the Applicant's claimed range. <u>A mere statement that something is desirable, without a way of how to achieve such a</u>

result, does not constitute an enabling disclosure. Also, a mere statement that something is desirable, does not make it achievable to one of ordinary skill in the art. The general conditions for achievement of very low loss (e.g., less than 50 dB/km, or less than 20 dB/km) for PBG fibers were disclosed by the Applicants and were not known to one of ordinary skill in the art, nor were disclosed by the Libori reference, although the was a long felt need to have a fiber with these characteristics.

IV. Finally, as stated above, Claims 25-27 call for the "optical fiber is configured to support a temporal soliton having a peak power of greater than about 1 MW". Such fiber is not obvious for the reasons discussed above, is not disclosed by the Liborui reference, and the reference provides no teaching that would lead someone to a fiber with this characteristics.

Accordingly, claims 1-3, 5, 6-10, 13, 14, 16-18 and 25-27 are not unpatentable over Libori, et al.

V. Furthermore, the Examiner (see pg. 5 of the Office Action) stated that figures 1 and 2 of the Libori reference teach PGB structure. However, since these figures clearly show a solid core, the fibers of Libori's Figures 1 and 2 can not be PBG fibers. The Examiner also referred Applicants to Fig. 5 of the Libori reference. Again, since this figure clearly shows a solid core, the fiber of Libori's Figure 5 can not be a PBG fiber (it will not have a photonic band gap).

Claims 1, 4, 6, 7, 12, 15, 19, 20, 22 and 23 are rejected under 35 USC 103(a) as being unpatentable over Fajardo et al (US 6,444,133 B1).

I. Claims 1, 4, 6, 7, 12, 15, 19 and 20 call for an optical fiber that guides the optical energy in a mode having a nonlinear refractive index of less than about 10^{-18} cm^2/W. As explain above, the fact that a fiber (such as Fajaro fiber) has a hollow core, doe not mean that the fiber satisfies this condition. As known to one skill in the art, because the mode propagates

in the core and in partially in the cladding. Accordingly, because the nonlinear refractive index of the mode depends on the refractive index of the core and that of the cladding, claims are claims 1, 4, 6, 7, 12, 15, 19 and 20 are not obvious over the Fajardo reference. It is noted that the Fajardo reference does not disclose FBG fibers that are capable of satisfying this condition, nor teach or suggest that the claimed condition can be satisfied, nor teach, suggest or discuss any fibers capable of guiding the modes such that the overlap between the mode and the cladding is only a fraction of 1%.

Claim 20 depends from claim 19 as its base claim and is even more stringent, requiring a factor of 2 improvement –i,e., it calls for "optical signal is guided in a mode having a nonlinear refractive index of less than about 5 x 10^{-19} cm^2/W ". No such fibers are shown or even suggested by the Fajardo or any other cited references.

Claims 22 and 23 depend from claim 19 as their base claim, and therefore explicitly incorporate a subject matter of claim 19. Therefore, claims 22 and 23 are not obvious over the Fajardo for the same reasons that claim 19 is not obvious over this reference.

II. With regard to claims 22 and 23, the Fajardo reference does not disclose the fiber with ether a loss of a loss of less than about 300 dB/km, less than 50 dB/km, etc, or that has a nonlinear refractive index of less than about 10^{-18} cm^2/W, or less than $5x10^{-19}$ cm^2/W. The low loss feature (not disclosed by the Fajardo reference) in combination with the low nonlinearity (also not disclosed by the reference), where the claimed nonlinear refractive index at least one to two orders of magnitude smaller than similar known fibers (and certainly not within general ranges disclosed by prior art fiber references), make applicants claims unobvious 22 and 23 over Fajardo, and other the cited references.

Claims 21 and 24 are rejected under 35 USC 103(a) as being unpatentable over Fajardo et al (US 6,444,133 B1) as applied to claims 1, 4, 6, 7, 12, 15 19, 20, 22 and 23 above, and further in view of Libori et al (US 6,792,188 B2).

Claims 21 and 24 depend from claim 19 as their base claim, and further call for solitons.

Claims 21 and 24 being dependent claims explicitly incorporate a subject matter of claim 19. Therefore, claims 22 and 23 are not obvious over the Fajardo for the same reasons that claim 19 is not obvious over this reference.

Furthermore, as described above, just because PBG fiber has an air core does not mean that it can support soliton propagation, because the fiber also has a cladding, and there is interaction between the mode and the cladding. Futhermore, column 1, lines 13-20 of Libori are directed to "conventional" fibers, and not to PBG fibers. Libori does not teach that any of its disclosed embodiments of PBG fibers supports solitons. The Examiner stated (see pg. 7 of the Office Action) that "It would have been obvious to one of ordinary skill to modify the Fiber of Fajardo et al to support solitons as taught by Libori et al". However, the Libori refernce does not teach how to make such modification.

Conclusions

Based upon the above amendments, remarks, and papers of records, applicant believes the pending claims of the above-captioned application are in allowable form and patentable over the prior art of record. Applicant respectfully requests that a timely Notice of Allowance be issued in this case.

Applicant believes that no extension of time is necessary to make this Reply timely. Should applicant be in error, applicant respectfully requests that the Office grant such time extension pursuant to 37 C.F.R. § 1.136(a) as necessary to make this Reply timely, and hereby authorizes the Office to charge any necessary fee or surcharge with respect to said time extension to the deposit account of the undersigned firm of attorneys, Deposit Account 03-3325.

Please direct any questions or comments to Svetlana Z. Short at 607-974-0412.

Respectfully submitted,

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